CHAPTER 4.4 FRESHWATER PROBABILISTIC MONITORING RESULTS

Summary

Section 305(b) of the Clean Water Act directs states to report on the water quality status of all waters every two years. In addition, State Water Control Law (§ 62.1-44.19:5) requires the Virginia Department of Environmental Quality (DEQ) to provide an accurate and comprehensive assessment of the quality of state surface waters using accurate and comparable data that is representative of the state as a whole. Probabilistic Monitoring (ProbMon) is designed to answer questions about statewide water quality conditions, through the use of a statistically valid sample frame across large geographic areas, whereas targeted ambient monitoring is designed to only capture local conditions. DEQ has sampled 735 wadeable sites statewide for the ProbMon program since it began in 2001. Over 260 sites were sampled during the 2018 assessment period. Although the majority of water quality parameters meet applicable water quality criteria, the biological condition of Virginia streams fail to meet expectations in approximately 47 percent of stream miles in Virginia. Biological condition is assessed using aquatic organisms as indicators of stream health. These biological impairments are believed to be caused in part by deteriorating environmental conditions that are not subject to water quality criteria. This is supported by the result that the 3 most commonly encountered water quality problems in this investigation; streambed sedimentation, habitat disturbance, and total phosphorus have no such criteria. In addition to the required reporting elements, ProbMon is a cost-effective way to test new sampling methods and support other DEQ water quality management activities like water quality standards development, Total Maximum Daily Load (TMDL) studies, and setting more defensible permit conditions.

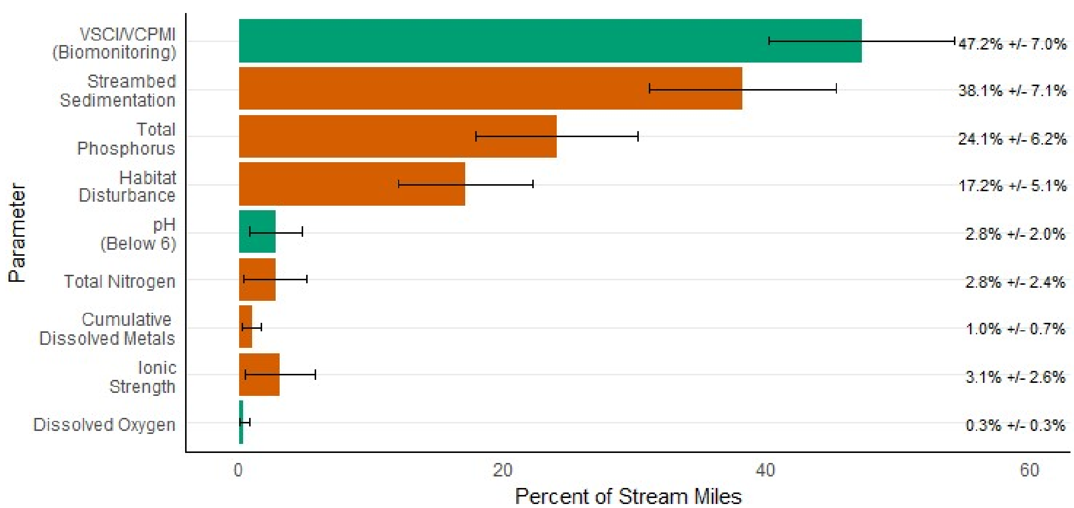

Figure 4.4-1. Percentage of stream miles with water quality parameters exceeding criteria/screening values. Red bars indicate a parameter with no water quality standard and green bars indicate a parameter with water quality standard or screening value. Parameter represents data collected from 2011 - 2016.

Introduction

Probabilistic monitoring is designed to answer basic questions like: “What are the primary water quality problems in Virginia? How widespread are these problems, and what pollutants cause the greatest environmental stress to Virginia’s water resources?” The Virginia General Assembly, citizens, environmental stakeholders, and the United States Environmental Protection Agency (EPA) have encouraged the Virginia Department of Environmental Quality (DEQ) to answer these questions and to establish baseline water quality conditions for Virginia’s streams and rivers. Every two years, DEQ is required to report on the status of all State waters to EPA through the 305(b)/303(d) Integrated Report process. All available water quality monitoring data collected during the assessment cycle should be considered. ProbMon is one component of DEQ’s Water Quality Monitoring Strategy. Typically water quality monitoring stations are located at bridges, boat ramps or other public access points, or focus on a known or suspected source of pollution. These monitoring stations are known as targeted ambient monitoring sites and can only best provide a local view of water quality conditions. Targeted ambient monitoring has great utility for identifying impaired waters, supporting Total Maximum Daily Load (TMDL) and Implementation Plan modeling efforts, monitoring water quality trends over time, tracking local pollution events, and monitoring regulatory compliance of pollution sources. However, it is not appropriate to interpolate results from targeted stations to un-sampled watersheds over large geographic areas. Data to address water quality questions from large geographic areas are best obtained from statistically designed studies with randomly chosen sample locations.

In Virginia, ProbMon sites are randomly selected using EPA’s probability survey design program (Stevens 1997; USEPA 2006). From January 1st, 2011 until December 31st, 2016 DEQ evaluated 444 sites and sampled 261 stations (Figure 4.4-2). From 2001 to 2016, DEQ has evaluated over 1100 stations and sampled 735 sites (Figure 4.4-3). In some cases, stations were evaluated, but not sampled for one of a variety of reasons (e.g. the stream was not perennial, it was saltwater influenced, or the landowner denied access). DEQ samples 50 to 60 random stations per year throughout Virginia for a variety of chemical, biological, and habitat parameters as detailed further in this Chapter.

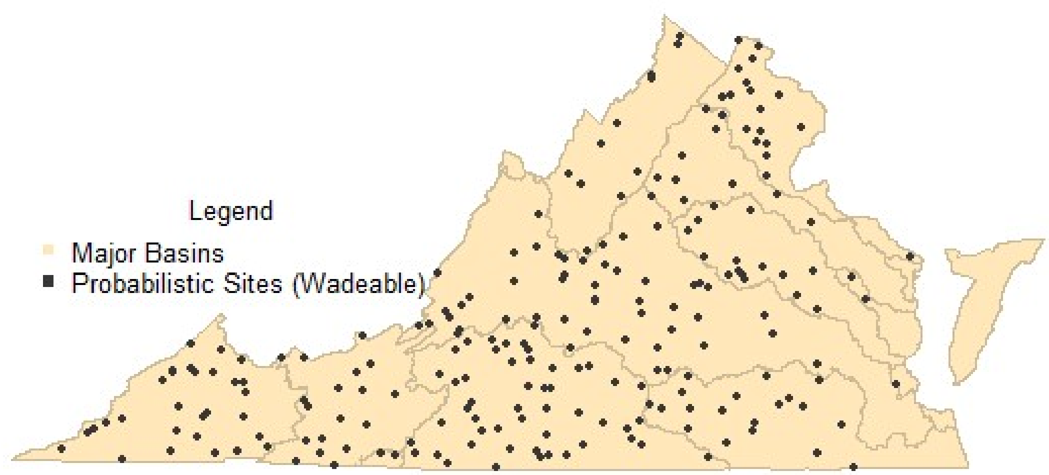

Figure 4.4-2. Virginia probabilistic monitoring locations from 2011 – 2016 (number of stations (n) = 261).

The sampling frame provided by EPA for Virginia streams and rivers includes 49,100 miles. It is important to note that the total amount of assessed river miles may vary to some extent by parameter. This number varies based on whether a monitoring tool was appropriate for the sampling location. For example, DEQ biological monitoring tools are not validated for streams without a defined channel, thus streams dominated by wetlands cannot be assessed (approximately 5,000 miles). The actual number of target stream miles (perennial, flowing freshwater) is much less because several thousands of stream miles are not perennial (e.g. the stream was dry when DEQ visited) or were found to be saltwater influenced. There is an estimated 1,200 miles of non-wadeable streams (also referred to as boatable sites), which must be sampled using large river habitat and biological sampling methods. Non-wadeable and wadeable sites, and associated watersheds, sampled since 2001 are presented in Figure 4.4-4. Large river data collection, using a non-wadeable (boatable) methodology, is underway and the condition will be included in future 303(d) / 305(b) Integrated Report chapters. The ProbMon chapter provides estimates for all perennial, non-tidal, wadeable stream and river miles which equates to approximately 41,500 miles.

The total stream miles affected by a reported parameter is evaluated by determining the proportion of samples in a given basin of each stream size that are affected, then extending these proportions to the total number of stream miles in each basin. These totals are added to give statewide totals. Estimates of percent river miles not meeting water quality criteria or established screening values are reported with 95 percent confidence intervals.

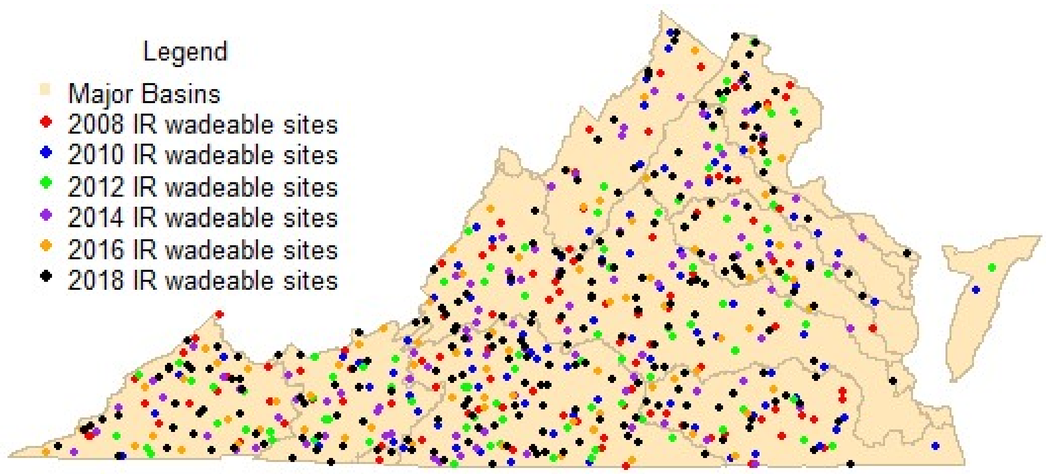

Figure 4.4-3. Virginia probabilistic monitoring wadeable locations from 2001 - 2016 (n = 735).

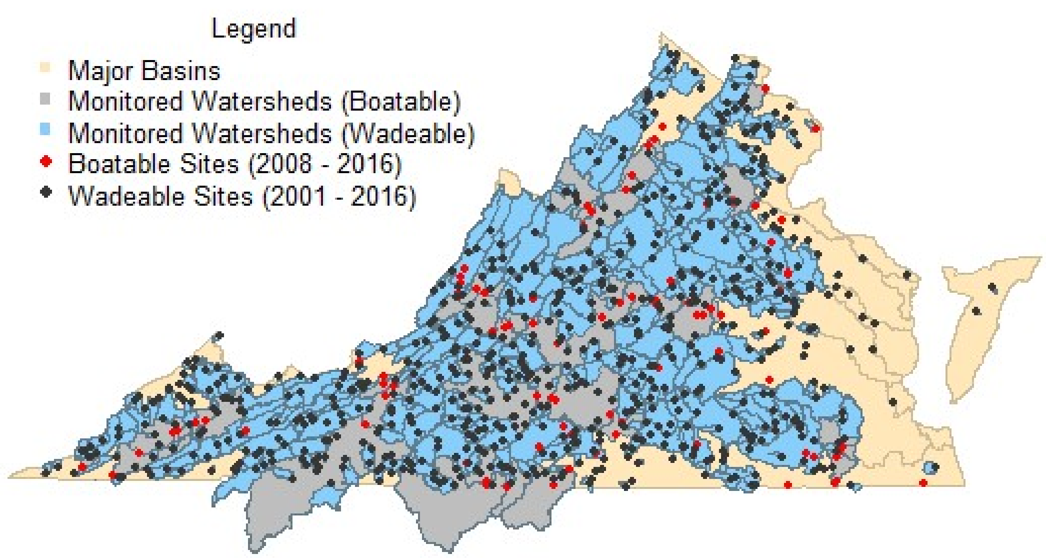

Figure 4.4-4. Virginia probabilistic monitoring wadeable and boatable watersheds and sample sites from 2001 - 2016 (n = 819).

Parameters with Water Quality Standards or Screening Values

Dissolved oxygen, pH, temperature, metals (dissolved and sediment), organic chemicals, and bacteria have applicable water quality criteria or screening values. Water quality standards are regulatory thresholds developed to protect water quality conditions in support of swimming, fishing, and aquatic life designated uses. Screening values are non-regulatory thresholds used to interpret select water quality parameters. Overall results are summarized in Figure 4.4-1 and individual parameter results are discussed below.

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important measures of water quality for aquatic organisms. Adequate DO is a fundamental physiological requirement for aquatic life. In streams, the DO concentration may be altered by photosynthesis, respiration, nutrient input, re-aeration, and temperature, all of which have seasonal and daily cycles. This natural variability is reflected in the stream classification component of Virginia's Water Quality Standards (9 VAC 25-260, Commonwealth of Virginia 2017). For example, a mountain stream that supports native trout is expected to have higher DO than a low-gradient, warm water stream. Although expectations for DO concentration vary, all waters (excluding swamps) in Virginia are required to have a DO concentration of 4 mg/L or above. DO standards can be determined on a case-by-case basis if DO deviates due to natural conditions as in swamps and other wetlands (Commonwealth of Virginia 2017). Pollution plays an important role in dissolved oxygen concentration. Human and animal wastes released into streams provide nutrients which cause excessive growth of algae and aquatic plants. As microbes break down organic matter produced by algae and plants, their respiration can deplete the available DO and the aquatic biota may become stressed and die due to low DO concentration.

ProbMon results indicate that DO conditions for the majority of Virginia's streams and rivers are above the minimum value of 4 mg/L, with only 0.3 percent of results within the 2018 assessment period below the standard. Most stations with values below 4 mg/L are located in coastal ecoregions where the DO is naturally lower due to swamp conditions. These sites with low DO need to be reviewed as candidates for site specific DO standards. ProbMon results suggest that the majority of mountainous zone waters, stockable trout waters, and natural trout waters are meeting DO standards. Estimates are reflective of an average of two data points, where data are available.

pH

pH measures the concentration of hydrogen ions in water or the amount of acidity present. Since the pH scale is logarithmic to base 10, a decline in pH by one unit indicates a tenfold decrease in hydrogen ions. At pH 7, a solution is neutral whereas pH values below 7 indicate acidic conditions and values above 7 indicate basic conditions.

Stream pH depends on local geology, ecology, and anthropogenic influences. If a stream has poor buffering capacity as is the case for a stream flowing over granite or shale, it may be naturally acidic. In the case where inorganic acids such as sulfuric or nitric acid are introduced via rain, the low buffering capacity can be rapidly exhausted and the pH declines. The resulting low pH may be detrimental to aquatic biota unaccustomed to low pH. pH values harmful to aquatic life are below 6 or above 9. This range is reflected in Virginia's Water Quality Standards, where most waters must fall within a pH range of between 6 and 9. Natural pH values of 5 or below occur in swamp waters and should not be considered harmful to the native fauna common to those ecosystems. pH standards can be determined on a case-by-case basis if pH deviates due to natural conditions as in swamps and other wetlands (Commonwealth of Virginia 2017).

ProbMon results show that 2.8 percent of wadeable Virginia streams and rivers are estimated to have pH below 6. All stations with deviations in pH occurred at sites located in the coastal ecoregion where swamp waters are common, which indicates the need to continue revising site specific water quality standards. DEQ collects additional parameters, including Acid Neutralizing Capacity (ANC) and sulfate data at ProbMon stations to estimate the percent of streams impacted by acid rain and acid mine drainage. High sulfate values in low pH streams are indicative of acid mine drainage whereas streams with low ANC values are susceptible to episodic acidification from acid rain runoff (USEPA 2000). However, based on ProbMon data collected during the 2018 assessment period, DEQ estimates that no pH values were below 6 in the mountain ecoregions. Estimates are reflective of an average of two data points, where data are available.

Temperature

Temperature affects water quality by potentially imposing a heat burden on aquatic life and by limiting the level of dissolved oxygen in water. Temperature in streams varies in relation to seasonal and daily changes. Sunlight is the primary source of temperature change. Stream temperature is also influenced by the temperature of the stream bed, groundwater inputs, and air in contact with the water surface. Temperature is inversely related to bank vegetation cover as less cover results in more exposure to the sun and higher instream temperatures. Also, runoff from impervious surfaces in urban areas may increase water temperature. Finally, effluent that is discharged to a waterbody may have a higher temperature than the receiving stream and, therefore, may elevate instream water temperature.

Stream temperature can directly influence the types of organisms found in an aquatic system as well as their growth, behavior, metabolism, reproduction and feeding habits. Virginia's temperature standards reflect the upper limit to support different forms of aquatic life (9 VAC 25-260, Commonwealth of Virginia 2017). Standards for temperature vary, notably in cold water fisheries, but as a general rule, all waters in Virginia are required to have a temperature at or below 31 or 32 degrees Celsius.

Overall, DEQ estimates that temperature violations will be rare in Virginia's wadeable streams during the spring and fall, as there were no results recorded above the standard during the assessment period. However, it is important to note that ProbMon temperature data is seldom collected during the most stressful hydrologic and weather conditions. Estimates are reflective of an average of two data points, where data are available. In order to properly estimate temperature problems, temperature data must be collected continuously. Continuous temperature data collection began in 2016 at twenty probabilistic trend sites.

Dissolved Metals

Dissolved Metals have been identified as an important influence on benthic community structure in streams (Clements et al. 2000). Some taxa appear to be relatively tolerant to metals while other taxa are intolerant of metals. Metals are most biologically available and toxic when dissolved in water. Toxicity of many metals is dependent on water hardness, or the amount of minerals in the water, making it necessary to calculate site specific water quality criteria from hardness values. Table 4.4-1 lists the Virginia Water Quality Criteria for metals assuming a hardness (expressed as $CaCO_3$) of 100 mg/L for most dissolved metals. The table also summarizes the number of sites that had detectable analytical results and the number of criterion exceedences based on site specific hardness values.

All criteria are calculated using site-specific hardness measures. No samples were measured above their respective chronic or acute sample criteria during the 2018 Integrated Report sample window (2011 - 2016). Results are shown in Table 4.4-1.

Table 4.4-1. Dissolved metals results (2011 - 2016, n=255) compared to Virginia's Water Quality Standards. ppb[1] = parts per billion

Metal	DEQ Acute Criteria (ppb[1])	DEQ Chronic Criteria (ppb[1])	# Above Criteria	% of Miles Above Criteria
Arsenic	340	150	0	0% (+/- 0%)
Cadmium	3.9 $CaCO_3$=100	1.1 $CaCO_3$=100	0	0% (+/- 0%)
Chromium	570 $CaCO_3$=100	74 $CaCO_3$=100	0	0% (+/- 0%)
Copper	13 $CaCO_3$=100	9 $CaCO_3$=100	0	0% (+/- 0%)
Lead	120 $CaCO_3$=100	14 $CaCO_3$=100	0	0% (+/- 0%)
Mercury	1.4	0.77	0	0% (+/- 0%)

Nickel	180 $CaCO_3$=100	20 $CaCO_3$=100	0	0% (+/- 0%)
Selenium	20	5	0	0% (+/- 0%)
Silver	3.4 $CaCO_3$=100	NA	0	0% (+/- 0%)
Zinc	120 $CaCO_3$=100	120 $CaCO_3$=100	0	0% (+/- 0%)

Bacteria

Escherichia coli (E. coli) bacteria are found in the intestines and fecal matter of warm-blooded animals. High counts of E. coli bacteria in a stream indicate that there is an elevated risk of illness from pathogenic organisms. According to Virginia's Water Quality Standard for E. coli, a stream should not exceed a geometric mean (for two or more samples taken within a calendar month) of 126 colony forming units (cfu) per 100mL of water or an instantaneous maximum of 235 cfu/100mL (Commonwealth of Virginia, 2017).

A DEQ bacteria impairment listing is determined based on a temporal dataset where bimonthly bacteria samples are collected from a single site over two years. Bacteria are only sampled once at each ProbMon site. Site specific bacteria problems are best characterized by repeated samples over several months as is the approach in DEQ's ambient monitoring program. For this reason, bacteria results from the freshwater ProbMon program and ambient monitoring program are not comparable and as such the results are not presented.

Beginning in 2013, DEQ sampled bacteria monthly at probabilistic monitoring sites that met certain criteria. Monthly sampling efforts will allow DEQ to make temporally accurate bacteria estimates, which will be included in future reports.

Parameters Reported in Past Cycles

Sediment Metals

DEQ collected 492 sediment metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc) samples from 2001 through 2012 and reported results in the 2008, 2010, 2012, and 2014 Integrated Reports. Sediment metals concentrations were below Probable Effects Concentrations (PECs) and affected a low percentage of stream miles. Due to the low prevalence of metals above PECs in Virginia's wadeable streams and high sampling costs, DEQ has suspended sediment metals sampling. Consequently DEQ will not report on sediment in the 2018 assessment cycle.

Organic Chemicals in Sediment

In 2001 and 2002, DEQ collected organic chemicals, organic pesticides, polychlorinated biphenyls, semi-volatile constituents, and herbicides in sediment but the data were not analyzed at a low enough detection limit to provide useful information. DEQ collected 209 organic chemical samples (total PCB, total PAH, heptachlor, chlordane, dieldrin, lindane, endrin, DDT, DDD, DDE, Total DDT, anthracene, chysene, fluoranthene, naphthalene, phenanthrene, pyrene, benzoanthracene, benzo-a-pyrene) in sediment samples from 2003 through 2006 and reported results in the 2008 and 2010 Integrated Reports Probabilistic Monitoring chapters. A low percentage of wadeable stream miles had concentrations above PECs. Due to high sampling costs, DEQ will not report on organic chemicals during this assessment cycle.

Integrated Report chapters from previous assessment cycles contain estimates of sediment metals and organic chemicals in sediment. Previous ProbMon chapters can be found online at: http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/ProbabilisticMonitoring.aspx#reports.

Biological Monitoring

Biological monitoring, or biomonitoring, of streams and rivers is an integral component of DEQ's water quality monitoring program. Biomonitoring allows DEQ to assess the overall ecological condition of streams and rivers by evaluating stream condition with respect to suitability for support of aquatic communities. In Virginia, benthic macroinvertebrate communities, or organisms that live on the bottoms of streams and rivers that are large enough to be seen with the naked eye and have no backbone, are used as indicators of ecological condition and to address the question of whether a waterbody supports the aquatic life designated use.

DEQ uses multi-metric macroinvertebrate indices, specifically the Virginia Stream Condition Index (VSCI) and the Virginia Coastal Plain Macroinvertebrate Index (VCPMI), to assess the aquatic life use status of wadeable streams and rivers. The VSCI and the VCPMI are applied to biomonitoring data collected in freshwater non-coastal areas and freshwater coastal areas, respectively. These indices utilize several biological metrics that are regionally calibrated to the appropriate reference condition (DEQa 2006; DEQ 2013). Results are calculated into a single value, or score, that is sensitive to a wide range of stressors.

VSCI and VCPMI scores were scaled so that a VSCI score of 60 is comparable to a VCPMI score of 42, with streams scoring above these thresholds being considered in optimal conditions. Similarly, streams with VSCI scores below 50 or VCPMI scores below 30 are considered in suboptimal condition. VSCI scores less than 42 are considered severely ecologically stressed, scores between 42 and 60 are moderately stressed, while sites above 60 to 72 are thought to have good ecological conditions and sites with VSCI scores above 72 are considered to have excellent water quality and habitat conditions (DEQ, 2006a). Based on VSCI and VCPMI ProbMon results, DEQ estimates that 47.2 percent of Virginia streams and rivers do not fully support the aquatic life use (Table 4.4-5). It is important to remember that biological indicators represent long-term water quality conditions and respond to a variety of stressors.

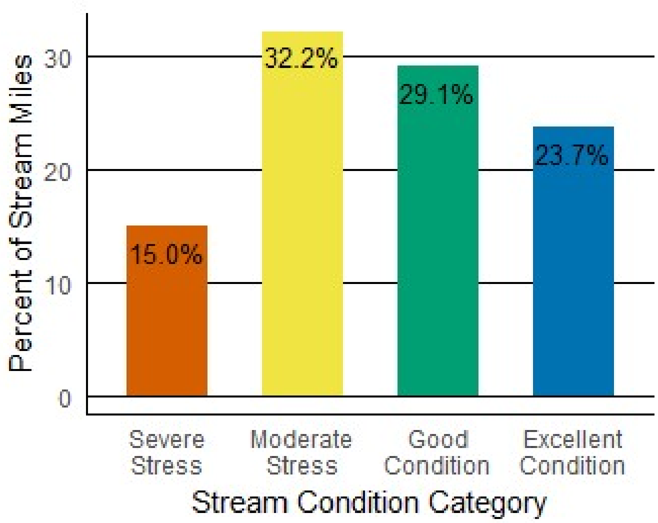

Figure 4.4-5. Biological stream condition index based on VSCI/VCPMI Scores (2011 - 2016, n = 261).

Parameters without Water Quality Standards

Stressors that increase the risk to benthic macroinvertebrate communities and do not have specific water quality standards include streambed sedimentation, habitat degradation, nutrients, ionic strength, and water column cumulative metals. Thresholds for the aforementioned stressors are presented in Tables 4.4-2 and 4.4-3 and are derived from literature values. The 'optimal' classification represents water quality conditions that are not associated with degraded aquatic communities. Stressors classified as 'suboptimal' increase the likelihood of finding an impacted aquatic community. The condition class between optimal and suboptimal is termed 'fair' as the stress to the aquatic community is less certain. In the following examples, water quality parameters without regulatory standards or criteria are presented using barplots. The barplots represent estimates drawn from data in the 2018 Integrated Report sample window (2011 - 2016).

Table 4.4-2. Thresholds of condition classes for biological indicators.

Response Parameters	Optimal	Suboptimal	Classification Reference
Virginia Stream Condition Index	> 60	<50	(DEQ 2006a)
Virginia Coastal Plain Macoinvertebrate Index	> 42	<30	(DEQ 2013)

Table 4.4-3. Thresholds of condition classes for stressor indicators[1].

Stressor Parameters	Optimal	Suboptimal	Classification Reference
Total Nitrogen (mg/L)	< 1	> 2	(DEQ 2006a)
Total Phosphorus (mg/L)	< 0.02	> 0.05	(DEQ 2006a)
Habitat Degradation (unitless)	> 150	< 120	(USEPA 1999)
Streambed Sedimentation (unitless)	> -0.5	< -1.0	(Kaufmann 1999)
Ionic Strength (TDS mg/L)	< 100	> 350	(DEQ 2006b)
Cumulative Dissolved Metals (unitless)	< 1	> 2	(Clements 2000)

Habitat Disturbance

Habitat is defined as the area or environment where an organism resides. It encompasses its surroundings, both living and non-living. Fish, aquatic insects, and plants require certain types of habitat to thrive, so in-stream and riparian (stream bank) habitat is evaluated when a biomonitoring sample is collected. Because organisms have differing habitat requirements, a variety of available habitat types in a stream or river will support a diverse aquatic community. Habitat is scored by evaluating ten habitat parameters and adding them together (total scores range from 0 to 200). Habitat scores above 150 indicate habitat conditions favorable for supporting a healthy aquatic community and are considered optimal. Scores lower than 120 are considered suboptimal and scores between 120 and 150 are fair (EPA 1999). As indicated in Figure 4.4-6, DEQ estimates that slightly over 34 percent of stream and river miles have available habitat that is considered optimal.

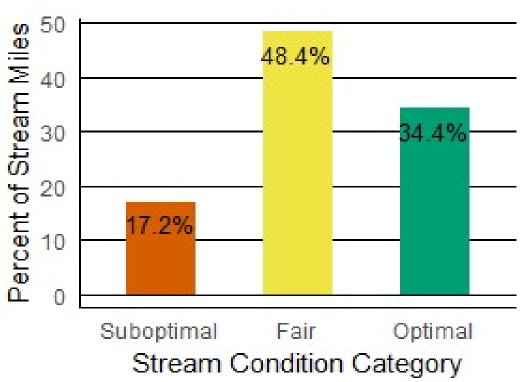

Figure 4.4-6. Estimate of Habitat Condition in Virginia Streams and Rivers. Data presented are from 2009 - 2014 (n = 261).

[1] The relative risk screening values presented in Table 4.4-3 do not represent water quality criteria nor are intended for establishing TMDL endpoints. The values represent an increase in the probability of stress to benthic communities.

Streambed Sedimentation

Excessive sedimentation can have pronounced impacts to benthic communities. Excess sediment fills interstitial spaces in the stream substrates used by aquatic organisms, disturbs refuge areas, and can potentially smother the organisms. Until recently, tools for quantifying sedimentation impacts in streams have been inadequate. Methods existed for describing dominant instream particle size, but it was difficult to differentiate between natural conditions and man-made problems. Virginia has a variety of stream types; many are naturally sand/silt bed streams, so simply measuring the size of the sediment particles cannot differentiate natural and human-influenced sediment load.

DEQ uses the relative bed stability (RBS) method for predicting the expected substrate size distribution for streams (Kaufmann 1999). RBS incorporates stream channel shape, slope, flow, and sediment supply. The method calculates a 'stream power' based on channel measurements to predict the expected sediment size distribution. The ratio of the observed sediment to the expected sediment is a measure of the RBS. A stream with a log RBS of less than -1 is carrying excess sediment while streams above -0.5 have a normal sediment load (Kaufmann 1999 and USEPA 2000). Over 38 percent of Virginia's stream and river miles have suboptimal sedimentation values (Figure 4.4-7).

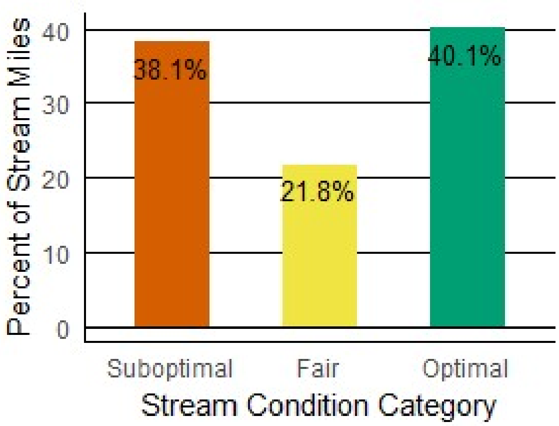

Figure 4.4-7. Estimate of streambed sedimentation conditions in Virginia streams and rivers as defined by LRBS measures. Data presented are from 2011 - 2016 (n = 239).

Nutrients

Nutrients are substances assimilated by living organisms that promote growth. Nitrogen and phosphorus are the two most important nutrients in Virginia streams and rivers. Excess nutrients can stimulate in-stream plant and algal growth. Characteristics of nutrient enriched streams may include low dissolved oxygen, frequent fish kills, shifts in aquatic communities favoring more pollution-tolerant species, and blooms of nuisance algae. Sources of nutrients are fertilized lawns and cropland, failing septic systems, municipal and industrial discharges, and/or livestock manure.

Total phosphorus above 0.05 mg/L and total nitrogen above 2 mg/L is considered suboptimal (Table 4.4-3) and can result in undesirable algae growth and shifts in aquatic communities (DEQ 2006a). DEQ estimates that only 40 percent of streams and river miles are classified as optimal for total phosphorus while over 84 percent of stream and river miles are considered optimal for total nitrogen (Figures 4.4-8 and 4.4-9).

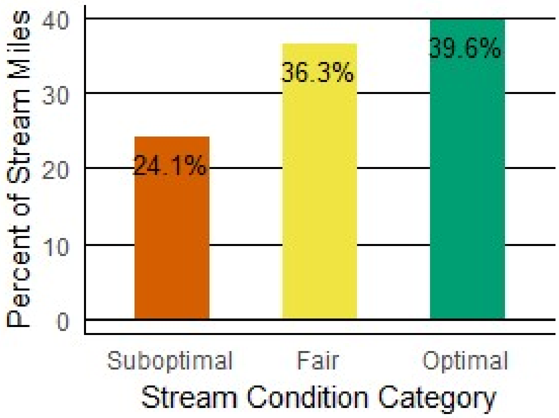

Figure 4.4-8. Estimate of Total Phosphorus Conditions in Virginia Streams and Rivers. Data presented is from 2009 - 2014.

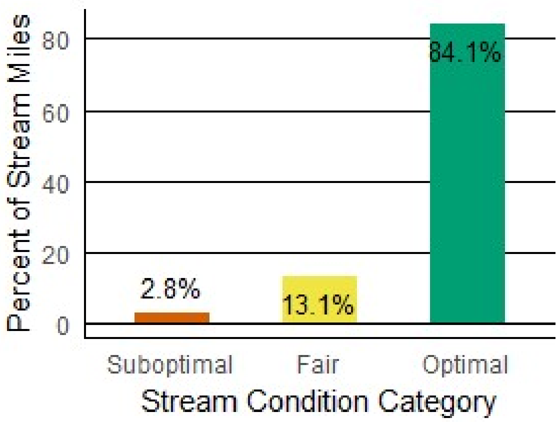

Figure 4.4-9. Estimate of Total Nitrogen Conditions in Virginia Streams and Rivers. Data presented is from 2009 - 2014.

Ionic Strength (Total Dissolved Solids)

Ionic strength varies with natural geology, but increases significantly in response to anthropogenic activities such as surface mining, road salts, or other industrial discharges. DEQ uses total dissolved solids (TDS) to measure ionic strength. Ionic strength is a measure of dissolved ions, dissolved metals, minerals, and organic matter in the water column. Water quality studies have consistently demonstrated that high levels of TDS in the water column impact aquatic life (DEQ 2006b). TDS levels above 350 mg/L increase the likelihood of having a degraded aquatic community and are considered suboptimal (Table 4.4-3). DEQ estimates that about 3 percent of Virginia streams have TDS levels in the suboptimal range (Figure 4.4.10).

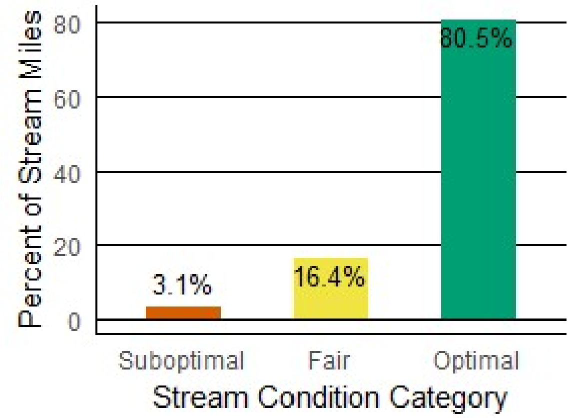

Figure 4.4-10. Estimate of Ionic Strength Conditions in Virginia Streams and Rivers. Data presented is from 2011 - 2016.

Cumulative Dissolved Metals (Cumulative Criterion Unit Metals Index)

Heavy metals such as mercury, chromium, cadmium, arsenic, and lead in streams and rivers can be harmful to aquatic insects at low concentrations. The metals tend to accumulate in the gills and muscles of aquatic organisms. Dissolved metals have been identified as important predictors of stream health. Toxicity of many metals is dependent on water hardness making it necessary to calculate site specific water quality criteria from hardness values.

In the context of water quality criteria, dissolved metals are typically treated independently; however there is strong evidence that metals have a cumulative effect (Clements 2000). Cumulative Criterion Units (CCU) account for this additive effect by standardizing each dissolved metal's concentration. The metals are summed together and the result is the CCU Metals Index score. When the CCU Metals Index is above 2, the cumulative effect is considered likely to harm aquatic life (Clements 2000). Nearly 1 percent of river miles in Virginia are estimated to have Cumulative Criterion Units that are considered suboptimal (i.e. CCU above 2; Figure 4.4-11; Table 4.4-3).

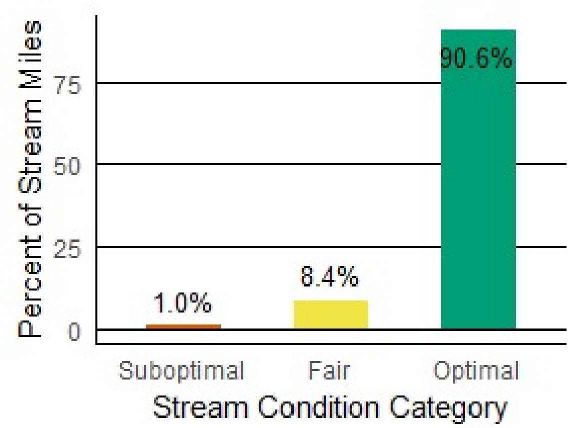

Figure 4.4-11. Estimate of Cumulative Criterion Unit Metals Index in Virginia Streams and Rivers. Data presented is from 2011 - 2016.

Relative Risk and Stressor Extent

One of the advantages of probabilistic datasets is the ability to calculate the relative risk (Figure 4.4-12) that different environmental stressors have on the ecological health of rivers and streams across large regions, and the stressor extent (Figure 4.4-13). Since the stations are selected at random, DEQ can estimate water quality parameter values over the entire state with known confidence. USEPA and other states have employed relative risk and stressor extent concepts extensively in their reports (ODEQ 2007; USEPA 2006; Van Sickle 2006; Van Sickle 2008).

Relative risk is a term borrowed from the medical field and applied here to communicate the severity of impact a stressor has on the aquatic environment. For example, it has been shown that an individual with total cholesterol above 240 mg/dl is at greater risk for heart disease than an individual whose cholesterol is below 200 mg/dl. When an individual has a cholesterol level above 240, their relative risk of having heart disease is higher than an individual with cholesterol level below 200.

The relative risks for aquatic stressors can be interpreted in a similar manner to the heart disease example. Figure 4.4-12 illustrates that the relative risk to the biological community due to habitat disturbance is 5.0; thus, the biological community is 5.0 times more likely to be considered suboptimal when habitat disturbance scores are below 120, (USEPA 1999). Relative risk values larger than 1 indicate an elevated risk to the biological community; consequently, only water quality stressors with a relative risk greater than 1 are reported in this chapter. pH was also evaluated for increased risk to the biological community but did not show significant relative risk to the biological community.

Calculation of relative risk requires classification of water quality responses (e.g. the benthic macroinvertebrate indices – Table 4.4-2) and the water quality stressors (Table 4.4-3) into optimal and suboptimal categories. DEQ classified biological response parameters based on the aquatic life use standard. The stressor indicators in Table 4.4-3 were classified using screening values from peer reviewed literature studies. It is important to remember that the stressor screening values are not equivalent to water quality standards in the Commonwealth of Virginia. This data-intensive statistical technique requires the entire probabilistic monitoring dataset (2001 - 2016).

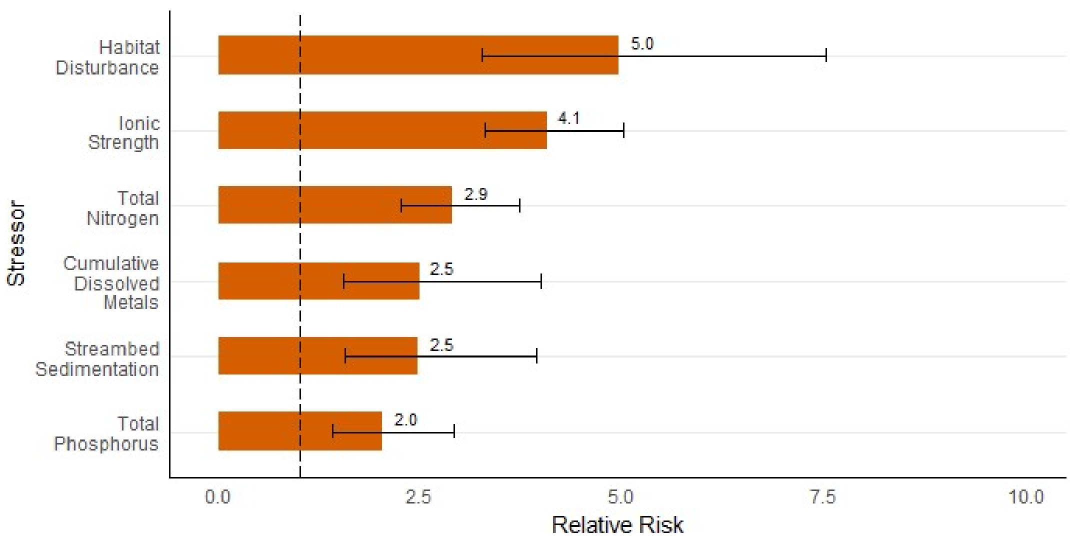

Figure 4.4-12. Relative Risk for major benthic macroinvertebrate stressors in all Virginia streams. The horizontal lines associated with the parameters illustrate the confidence intervals. The vertical dashed line at 1 indicates significance; thus, all relative risk estimates and confidence intervals that exceed the dashed vertical are significant. Relative risk shows the number of times more likely a benthic macroinvertebrate community is to be scored in the suboptimal range if the parameter shown on the y-axis is degraded. Data encompasses samples collected from 2001 - 2016.

Stressor extent shows how prevalent a stressor is in Virginia streams. The most common stressor across Virginia is streambed sedimentation. ProbMon data estimates streambed sedimentation is suboptimal in almost 38 percent of Virginia streams (Figure 4.4-13). When streambed sedimentation levels are suboptimal, relative risk analysis predicts they are 2.5 times more likely to have a suboptimal benthic community than streams with optimal sedimentation levels. Nearly 17 percent of Virginia streams have suboptimal habitat disturbance scores; suboptimal habitat disturbance scores increase the relative risk of a suboptimal aquatic community by a factor of 5.0.

The two major nutrients found in Virginia streams are nitrogen and phosphorus; their relative risks are 2.0 and 2.9, respectively. Suboptimal phosphorus conditions occur in many more streams (24.1 percent) than elevated nitrogen (2.8 percent). Ionic strength (as measured by total dissolved solids) has a relative risk of 4.1 which is one of the highest relative risks in the analyses. However, suboptimal ionic strength conditions were only found in 3.1 percent of Virginia streams. Dissolved metal concentrations that may cause adverse biological condition were found in 1.0 percent of Virginia streams; however, elevated dissolved metal concentrations increase the relative risk of having a suboptimal benthic macroinvertebrate community by 2.5.

Stressor extent presented in Figure 4.4-1 only focuses on the percent of stream miles deemed suboptimal by each of the major stressors to Virginia streams. Figure 4.4-13 encompasses the entire stream population for each stressor to relate a more complete narrative surrounding stressor extents in Virginia. Streambed sedimentation has the highest extent of stress in Virginia and nearly the same percent of stream miles in the optimal and suboptimal categories. As we have explored through previous visualization tools, streambed sedimentation, total phosphorus, and habitat disturbance are fairly widespread stressors statewide. Total nitrogen, water column metals, and ionic strength are fairly rare in Virginia with the majority of stream miles in the optimum category of their respective parameter.

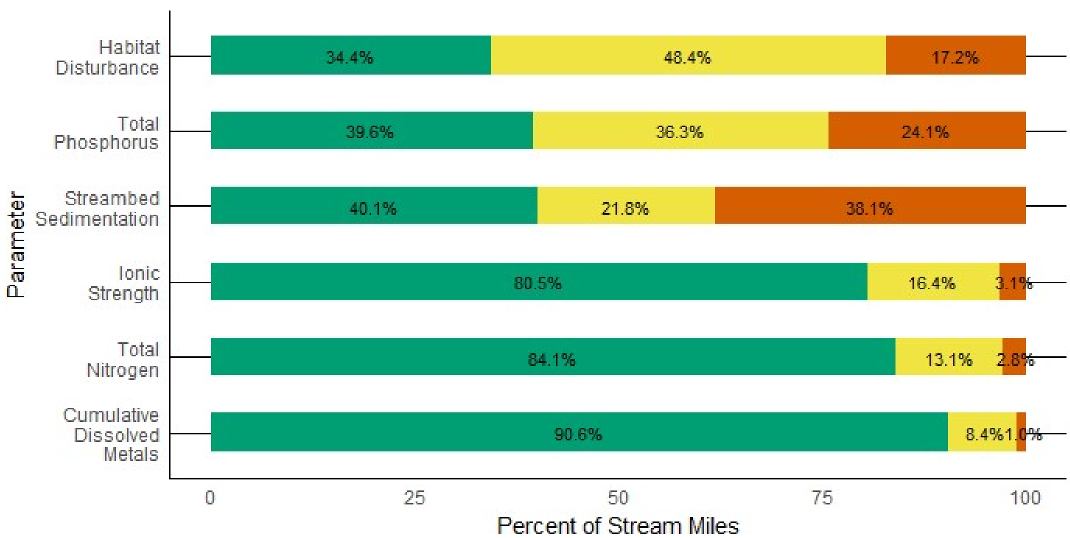

Figure 4.4-13. Stressor extent for major benthic macroinvertebrate stressors in all Virginia streams (2011 - 2016) showing all condition classes (optimal, fair, and suboptimal). Optimal condition estimates are shown in green, fair condition estimates are yellow, and suboptimal conditions are shown in red.

Uses of Probabilistic Data

In addition to estimating the condition of all streams and rivers for the biennial 305(b) assessment report and identifying the major stressors to aquatic organisms, freshwater ProbMon data has many ancillary applications within water quality management programs. Examples of these uses are discussed below.

ProbMon data is used in describing both the natural and baseline conditions of Virginia streams. In addition, ProbMon has helped identify minimally disturbed streams and understand their natural variability. This information is integral for DEQ to develop more regionally specific water quality expectations and in turn define reference conditions and select appropriate reference sites. ProbMon has also provided statistically defensible descriptions of stream conditions as of the beginning of this century. DEQ will find this baseline tremendously valuable for comparison in future assessments.

ProbMon data is currently being used in the stressor identification process in benthic macroinvertebrate TMDLs (DEQ 2017). Stressor analysis is the process whereby candidate causes of stress (or stressors) to benthic macroinvertebrate communities are evaluated. The purpose of the workgroup was to develop data collection recommendations and scientifically defensible screening values for categorizing potential stressors. ProbMon data is especially useful in describing statewide in-stream conditions for those parameters that do not currently have water quality standards. Understanding existing conditions for those parameters without water quality standards provides perspective on parameter data and a way to evaluate potential stressors. Relative Bed Stability and metals in water column CCU are examples of new tools that are applicable to benthic macroinvertebrate TMDL stressor analysis. Relative Bed Stability is currently being utilized to evaluate sedimentation as a candidate stressor. ProbMon data was used to develop stressor specific metrics to help TMDL staff identify stressor signals from impaired reaches and collect the appropriate water chemistry information.

The co-location of biological, chemical, habitat and landuse data at ProbMon sites also allows for the examination of multiple stressors such as dissolved metal CCUs. DEQ plans to explore the effects of multiple stressors in future reports. This information should aid TMDL development and provide insight into how biological communities and stressor parameters interact.

ProbMon data is also being used as a test platform for new monitoring approaches such as periphyton and fish community data collection. The collection methodology was designed and tested in tandem with the USEPA's National Aquatic Resource Survey (NARS). Until DEQ participated in the NARS sampling, habitat and biology data collection methodologies were not refined for large rivers. Now DEQ is collecting complete ProbMon datasets for large rivers and plans to report on the condition of this valuable freshwater resource. Because ProbMon provides biological, chemical, physical habitat, and land use information at each site, the dataset is indispensable for developing and improving biomonitoring tools.

The ProbMon dataset provided crucial data needed to fill in gaps during the development of the VSCI and the validation of both the VSCI and Coastal Plain Macroinvertebrate Index (CPMI) (Maxted 2000). Following the validation, VSCI assessment results were included in the 2008 Integrated Report. DEQ used ProbMon data to validate the CPMI. Specifically, ProbMon data was utilized to identify new reference sites in the coastal plain, check ecoregion best standard values, and select potential metrics that would help the CPMI detect benthic macroinvertebrate community stresses created by human activity. The effort resulted in a new, robust tool for evaluating benthic macroinvertebrate communities in the coastal plain regions of the commonwealth called the Virginia Coastal Plain Macroinvertebrate Index (VCPMI, DEQ 2013). The technical VCPMI document is online at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityMonitoring/ProbabilisticMonitoring/vcpmi.pdf . ProbMon also aided in improving the biomonitoring program by identifying over 100 new biological references sites, doubling the number of reference sites in the Virginia reference site database.

ProbMon sites are the platform for building a genus-level macroinvertebrate database which may ultimately be used in developing a more robust multi-metric assessment tool. ProbMon data may also be used to create a biological condition gradient for Virginia stream and rivers. The biological condition gradient is a descriptive model that illustrates how increasing stress alters ecological attributes (Davies and Jackson 2006). A biological condition gradient defines expected conditions, like benthic macroinvertebrate community structure, for streams by stream order and ecoregion. The biological condition gradient may help DEQ protect high-quality streams and provide stepwise interim goals for tracking water quality improvement.

Probabilistic data has been used to support water quality permitting decisions. DEQ establishes defensible background conditions in dissolved metal permit model by using the statistically derived baseline metal estimates for watersheds across the commonwealth. A workgroup has been formed to help deliver this information to the water permitting group at DEQ.

An important future application of ProbMon data is change analysis (Kincaid 2016). DEQ adjusted the experimental design of ProbMon by adding randomly selected sentinel sites in order to accelerate its ability to detect changes in population estimates. By revisiting a relatively small number of these randomly located sites each year, DEQ will be able to detect statewide and regional chemical, habitat, and biological changes. Perhaps the most important question a monitoring program addresses is: are management initiatives effective? The ability of ProbMon to detect shifts in population estimates is critical to the goal of evaluating the effectiveness of water quality management programs.

Conclusion

DEQ analyzed 14 water quality parameters with established water quality criteria and/or screening values and 6 parameters without water quality criteria. Most of the parameters that have water quality criteria meet applicable standards. The majority of water quality standard exceedences are attributed to legacy pollutants or natural conditions. The results presented in the ProbMon chapter reflect the success of DEQ's management of water quality parameters with water quality criteria.

Only biological monitoring results were found to be below screening thresholds in a relatively high percentage of streams. Benthic macroinvertebrate communities were degraded in 47.2 percent of the wadeable streams and rivers in Virginia; a percentage that could be considered widespread. Benthic macroinvertebrate communities are indicators of water quality problems because they respond to a variety of water quality stressors including parameters that have water quality standards (e.g. dissolved oxygen levels) and parameters that do not have criteria (e.g. such as nutrients and sedimentation). The following six stressors increase the risk to aquatic organisms and do not currently have water quality standards: streambed sedimentation, habitat disturbance, total phosphorus, total nitrogen, total dissolved solids, and cumulative metals in water column. These six major stressors do not currently have water quality standards, but most are being addressed through a variety of strategies such as nutrient management plans and best management practices. As the ProbMon program evolves and DEQ expands on the uses of ProbMon data, enhancement of the strategies for understanding, evaluating and restoring the commonwealth's streams and rivers will continue.

Presentations, posters, reports, and handouts about ProbMon are available for viewing and download at the following website:
http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/ProbabilisticMonitoring.aspx.

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